MANUFACTURE OF SWEET POTATO STARCH IN THE UNITED STATES

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The chemical research and engineering application involved in the erection and operation of a factory for production of starch from sweet potatoes are described with the objective of furthering the establishment in the United States of an industry to supply a part of the domestic requirements for so-called root starches. The properties of sweet potato starch were studied and evaluated from standpoint of use in various industries. The value of the by-product pulp as cattle feed was established, and in this role it might play an important part in southern agriculture. A new method of dehydration was evolved for making possible the storage of sweet potatoes and year-round operation of starch factories. This new method of dehydration makes possible additional sweet potato by-products and and also various grades of flour which can be used in a number of industries.

A summary is given of the lines of agricultural research which were undertaken in order to adapt the sweet potato crop to this new type of utilization. Chemical and mechanical equipment requirements for a sweet potato starch factory embodying the experience gained to date are outlined.

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The value of starches for direct industrial use is based predominantly on their physical properties after gelatinization or partial conversion in relation to the physical characteristics of materials treated, or mixed, with them. Starches from various plant sources differ in physical properties, and these differences are frequently important for industrial uses of certain types. The so-called root starches (potato, cassava, arrowroot, etc.) differ as a group in some important physical characteristics from the cereal starches (corn, wheat, rice, etc.). Cornstarch is the principal starch produced in the United States, but there is a definite need for root starches. This is shown by imports over a period of years (Table I) although price considerations also play a part.

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Table I. U. S. Production and Importation of Starches[a]
(In Thousands of Pounds)

Year	Production: Corn	White potato	Sweet potato	Importation: Cassava[b]	Sago[c]	White potato	All other[d]
1933	960,252	9,283	...	190,302	12,317	13,195	4,743
1934	.....	....	140	176,109	12,761	13,622	4,505
1935	756,281	33,778	250	202,112	24,806	8,387	5,026
1936	.....	....	420	269,504	36,434	12,670	5,535
1937	935,116[e]	9,380[e]	500	432,858	33,470	10,528	6,716

a Figures, except for sweet potato starch, taken from "Starch," published by Bureau of Foreign and Domestic Commerce, U. S. Department of Commerce, June 1938. Figures for production of sweet potato starch from Carbohydrate Research Division, Bureau of Chemistry and Soils.
b Figures are for tapioca (cassava), crude, flour, and prepared.
c Figures are for sago, crude and flour.
d Figures also include arrowroot flour.
e Preliminary.

White potato starch, produced in Aroostook County, Maine, and to a small extent in Minnesota, has been the only domestic root starch. [Florida arrowroot (Zamia floridana) starch was formerly produced in a small quantity in southern Florida.] This industry will be limited as long as it remains solely on a basis of cull (sometimes No. 2) potatoes. The commercial feasibility of developing a domestic white potato starch industry on the basis of potatoes grown specifically for starch, as in Europe, has not been demonstrate

In considering the possibility of establishing a domestic root starch industry to supply a large part of the requirements for starches of this type, thus supplementing the cornstarch industry in the Middle West, attention has been given to the sweet potato (Ipomoea batatas) as raw material. Pioneer experimental work in the United States on sweet potato starch was begun by the South Carolina Agricultural Experiment Station in 1895 and continued several years (11,16). In 1928 the LaFourche Starch and Refining Company, Thibodaux, La., produced sweet potato starch by a simple sedimentation process. German potato starch machinery was used and no chemical treatment was employed. The color of the starch was unsatisfactory and operation was discontinued, primarily because of failure to produce starch of suitable quality Starch has been obtained from sweet potatoes in Japan for approximately one hundred years by crude methods on a household and very small factory basis (7, 9); consequently, it is variable in quality and frequently off-color. In 1933 over 30 per cent of Japanese starch production was from this source (7).

White color is important in marketing starch; it was evident, then, that if a sweet potato starch industry were established in the United States, development of mechanical equipment for efficient large-scale operation and chemical treatment for elimination of color would be required. A process involving the use of sulfur dioxide in the grinding and screening systems

followed by extraction of pigments with alkali was originated by Balch and Paine (4). Later Thurber proposed the use of alkaline sodium sulfite solution in the milling and screening systems and in starch purification (26).

Erection of Factory

In 1934, following this research, the Federal Emergency Relief Administration actively considered the possibility of developing a sweet potato starch industry in the South. In case starch of suitable quality could be manufactured at satisfactory cost, the following factors would be of importance: (a) use as raw material of a crop well suited to southern soil and climatic conditions, particularly in the coastal plain section; (b) local production of the crop and consumption of starch in contiguous cotton mills with low transportation cost for raw material and products; (c) availability of a carbohydrate feed (residual pulp) needed in the South for supplementing cottonseed meal for feeding beef and dairy cattle; (d) substitution of sweet potatoes for cotton in areas not best suited to cotton, which would relieve the situation created by decreasing cotton exports and use of substitutes; (e) benefit from greater use of a root crop in crop rotation systems in the South, similar to that derived from sugar beets in other sections; (f) assistance in solving the cutover pine land problem, since "sweet potatoes are particularly adapted to newly cleared lands, such as the cutover pinelands of the South" (18); (g) assurance of sufficient domestic supply of root starch in case of war; (h) accessibility to water for coastwise shipment of starch.

With a view to supplying immediate work relief and providing a better local market for the sweet potato crop, and with a longer range objective of possibly establishing an industry beneficial to southern agriculture, the Federal Emergency Relief Administration allotted funds in 1934 and 1935 for erecting, equipping, and providing working capital for a sweet potato starch factory. A factory with a capacity of 10 tons of starch daily (24 hours) was established at Laurel, Miss., for developing the process on an industrial scale and serving later as a commercial plant.

Fifty acres of land, on which were a steel-concrete sawmill building, two and a half stories high, 90 x 190 feet in area (with a 40 x 80 foot wing), a steel concrete shop building, and a well with a capacity of 300 gallons per minute were purchased from a lumber company which was discontinuing operation because of exhaustion of timber supply. After the main building was reconditioned, it was equipped as a starch factory, and the shop building was used as a warehouse. (This work was done under immediate direction of F. H. Thurber.) Selection and installation of equipment and factory operation have been under the supervision of the Bureau of Chemistry and Soils. Expenditures of funds were made by the Mississippi Emergency Relief Administration, to which the FERA grant was allotted. The property (held for the Mississippi Agricultural Experiment Station) was deeded to the Mississippi State Institutions of Higher Learning and was then leased to Sweet Potato Growers, Inc., a coöperative association of growers organized for the purpose of supplying sweet potatoes and manufacturing starch.

The commercial conduct of the business, including factory operation, is under the direction of an experienced manager employed by the coöperative association. Later (after liquidation of the Mississippi Emergency Relief

Administration), the Resettlement Administration and, subsequently, the Farm Security Administration, United States Department of Agriculture, assumed a relation to this enterprise which was an outgrowth of, and somewhat similar to, that of the Mississippi ERA.

Sweet potato varieties differ greatly in starch content and, since the Triumph variety has consistently the highest starch percentage of those grown in the United States for the food market, it was selected as the supply for the starch factory. A sweet potato curing and storage house for seed stock was erected, and steam-heated hot beds were installed for producing a portion of the plants required annually.

Machinery for root starch manufacture differs in some respects from that used for cereal starches. Since domestic root starch production had been confined to the Maine potato starch industry which operates in small units with predominantly home-made equipment, no domestic machinery manufacturer was prepared to supply complete equipment for this purpose. Instead of importing European potato starch machinery (the suitability of some items of which was doubtful), standard units developed in the United States for varied use were adopted. All these items had never been assembled before for coördinated use, and it was impossible to obtain all units with closely related capacities. Since changes in power requirements were anticipated with development of the process, it was decided to use motors and purchase electricity. A 125 h.p. return tubular, gas-fired boiler operating at 100 pounds per square inch pressure provides steam for the starch and pulp dryers and accessory purposes.

Potatoes are delivered from storage bins by flume to a soaking pit, 5 x 15 feet, containing a horizontal, slow-moving spiral and potato lifter, and then pass to a rotary washer, 4 feet in diameter and 20 feet long, with water spray (capacity, 120 tons per 24-hour day). Sawtooth drum rasps, used in the European potato starch industry, are not available in the United States, and hammer mill grinders were installed. The washed potatoes are transported by bucket elevator to a hopper, feeding the first hammer mill on the second floor. The ground potatoes pass over a system of washing screens to remove "free" starch and are reground in a second hammer mill; then the material is again passed over screens until practically all free starch is removed. Six electrical vibrating screens arranged for countercurrent operation were installed originally; these had insufficient capacity and were replaced during the 1935 season by an eccentric shaker screen system.

From the final (fifth) screen the pulp passes to the drying equipment (dewatering reel, press, and dryer). From the reel (37 inches in diameter and 15 feet long), serving as a last unit in the countercurrent screening system, the pulp passes to a continuous, roller type, dewatering press in which the rolls are forced against the filtering drum (5.5 feet in diameter and 24 inches wide) by hydraulic pressure mechanism. The pressed pulp is delivered by drag elevator to a rotary, steam-heated, countercurrent, tubular type dryer, 6 feet in diameter and 30 feet long. Capacities of these pulp dewatering and drying units are 5 tons of 10 per cent moisture pulp per 24-hour day.

Table II. Power Requirements of Various Units in The Laurel Starch Factory During a Typical Operating Period (1936 Season)

	H.p.[a]
Potato washer and elevator	8.0
Potato grinder, first hammer mill	55.0[b]
Potato grinder, second hammer mill	35.0[b]
Screening system (eccentric shaker screens)	15.0
Pumps in connection with screening system	12.0
Pump, well water	16.3
Pumps (additional water)	13.0
Pump, flume	3.2
Pump, starch flushing	9.3
Pump, starch dust collector	4.8
Pumps, miscellaneous	10.0
Pulp press	3.0
Pulp dryer	9.8
Centrifuges, imperforate basket (each)	27.0
Centrifuge, perforate basket	27.0
Agitators, pulp tanks	18.0
Agitators, starch milk tanks	32.0
Starch elevators, wet	3.7
Starch elevators, dry	2.4
Starch mill	5.7
Starch sifter	7.0

a Power requirement for total connected load is 529 h.p.; normal operating cycle load is 422 h.p.; at 2000 bushels of potatoes per 24 hours, 2.1 kw-hr. are required to process 1 bushel.

b Power requirement of hammer mills varies with the screen mesh and proportion of water present.

Starch milk from the countercurrent screening system is passed over screens to remove fiber, etc., and is then pumped onto tables; there are thirty of these tables, 19 inches x 110 feet, 1/32-inch slope per foot, concrete construction (placement by Gunite method), with steel frames on steel rollers to permit expansion. After sedimentation the starch is flushed from the tables with fresh water and retabled. The second table starch is flushed off at 10-14° Bé. and is pumped to finishing tanks supplying a dewatering perforate-basket centrifuge. In the original installation, starch from the final screens was freed from "fruit water" in imperforate-basket centrifuges prior to tabling. This step is eliminated in the present process, and starch from the first and second table overflow is separated in these centrifuges.

The centrifuges have a 40-inch basket diameter and a speed of 1200 r.p.m., and are the suspended bottom-discharge type. The imperforate-basket centrifuges have three horizontal baffles to prevent surging of liquid.

The perforate-basket dewatering centrifuge has two horizontal baffles, which permit its use both as a filtering and as an overflow machine during the filling period and thus shorten the operating cycle (a type of construction developed at the Laurel factory). Machines of both types have manually operated, counterbalanced, serrate, plow-type unloaders designed to unload each section of the basket separately. The imperforate-basket machines unload directly into tanks in which the starch is mixed with water for pumping. The perforate-basket centrifuge unloads into a hopper leading to a screw and bucket conveyor system which delivers the moist starch to the mixer feeding the dryer. With a 12° Bé. starch milk feed the perforate-basket machine delivers 35 percent water-content starch equivalent to about 14.5 tons of finished, 12 per cent water-content starch per 24 hours.

The starch dryer, of batch vacuum type, 4 feet in diameter and 20 feet long, is operated at 28-inch vacuum with a finished starch load of 3000 pounds, average drying cycle 2.75 hours, capacity 12 tons finished starch per 24 hours, and steam consumption 1.29 pounds per pound of water evaporated. From the dryer the starch passes through a pulverizing mill with screens. The power requirements of the Laurel factory are shown in Table II.

Process Employed

The alkaline sodium sulfite process (26, 27), which had given promising results on a pilot-plant scale, was used during the 1934 season, but difficultie arose in adapting it to industrial operation. These were due to frequent stoppage of the screens caused by coalescing and hardening of sweet potato "latex" on the surfaces, the partial closing of screen openings due to growth of microörganisms (e. g., production of mold filaments), and increasing hydration of the pulp as it progressed from screen to screen. The operation was thus difficult to control, and a final pulp was produced which was difficult to dewater with a roller press. Recourse was then had to use of sulfur dioxide in the milling and screening systems. In the presence of sulfur dioxide the latex, instead of being dispersed on the screens, hardens *in situ* in the pulp.

Use of this reagent controlled the growth of microörganisms at the screening station; but since this station, equipped with accessory iron pipes, pumps, and tanks, was designed for an alkaline medium, sulfur dioxide caused solution of excessive quantities of iron which discolored the starch when treated subsequently with an alkali for removal of pigments. Although starch of acceptable quality could be obtained with such a sulfur dioxide-alkali process, an excessive quantity of bleach (sodium hypochlorite) was required. This process was not satisfactory from an operating standpoint because of narrow permissible limits of sulfur dioxide concentration and loss of sulfur dioxide by volatilization in the countercurrent system of washing the pulp.

Flocculation results when sweet potato extracts are too strongly acidified. When this occurred in factory operation, some of the precipitate sedimented with the starch and caused poor table operation; hence care had to be taken that the sulfur dioxide concentration was not too high. Yet it was necessary to maintain a minimum concentration of sulfur dioxide throughout the screening system in order to prevent excessive imbibition of water by the pulp and accumulation of latex on the screens (as in the alkaline sodium sulfite and simple water processes). Because of corrosive action the sulfur dioxide process could be operated only by alteration of certain equipment. Alkalie

such as sodium hydroxide, cause excessive imbibition of water by the pulp with difficult handling in screening and dewatering operations.

The use of a clear, saturated calcium hydroxide solution (0.04 N), suggested by Richee, was effective in eliminating the technical difficulties of the previous operation. This reagent permits the use of iron equipment and a counter-current system of pulp washing, prevents excessive hydration of pulp and stoppage of screens by latex and growth of microorganisms, and permits efficient screening at increased capacity and easy dewatering of final pulp by a roller press. The crude starch milk is now tabled directly, eliminating the intermediate (imperforate-basket) centrifugal separation previously employed. Total cost of chemicals and quantity of sodium hypochlorite required for bleaching were reduced. This process was used with satisfactory results during the 1936, 1937, and 1938 seasons.

The beneficial action of calcium hydroxide is due to solution of pigments, to flocculation of certain sweet potato constituents (apparently by action of Ca^{++}), and to production of pulp of favorable consistency. A portion of the sweet potato pigments is retained by the pulp and thus removed from the process instead of being dispersed in the starch milk. The settling rate of the material suspended in the starch milk is not greatly different from that of starch granules, and separation cannot be effected satisfactorily by tank sedimentation (probably also not by continuous hydroseparators) (30); but by tabling with suitable flow velocity, this material is floated off in the tailing water. Experience for three seasons has shown that calcium hydroxide causes little deteriorative action on silk screens in the presence of pulp and that 7XX bolting silk is suitable for pulp screening operations. This is an advantage, since metal wire screens cost more than silk screens and are difficult to mount without breakage under continued vibration.

In operating this process (public service patent application pending) at the Laurel factory, lime water is prepared by adding continuously, by motor-driven feeder, a sufficient quantity of hydrated lime to aerated well water to yield an approximately saturated solution (0.04 N) which is run into concrete settling basins for removal of insoluble calcium compounds and other precipitated substances. The clear lime water is pumped to the factory for use in the grinding and screening systems. A countercurrent scheme of pulp washing is used; i.e., fresh lime water is introduced at the tail end of the screening system (consisting of five sets of shaker screens, one reel and press) and then worked back to the first screen and grinder. Additional liquid (other than that provided as countercurrent water) must be added to the potatoes in the first grinder because of the difference in water content of fresh potatoes and of the pulp as it leaves the various screens; a small quantity of clear lime water is added at this point. Such a system builds up the "density" of the starch milk leaving the first set of shaker screens to approximately 5° Bé., which is ample for tabling. A flow diagram of the process is shown.

The crude starch milk passes through refining screens and into table supply tanks where a 2-hour reserve is maintained with continuous agitation. Such a lag between screening and tabling is beneficial in removing color from the starch. The starch milk is pumped to the tables at a rate (3 to 5 gallons per minute) to effect good separation of starch from flocculated material, fiber, etc. The density of the first tailing water is approximately 1.2° Bé., of which about 0.5° Bé. is due to starch and the remainder to "solubles" (principally sugars) from the potatoes.

Using a saturated calcium hydroxide solution as indicated, a pH of 8.6 to 9.2, the optimum range for all table operations, is maintained. If too much delay has not occurred in tabling and action of microörganisms has not been excessive, this reaction is automatically maintained. If the pH drops below the desired value, a small proportion of clear, saturated calcium hydroxide solution is added prior to tabling. The first table starch is flushed off with fresh water, adjusted to approximately 5° Bé., and retabled. The tailing water (0.5° Bé.) from the second tables contains a little starch. The second table starch is flushed off with fresh water, adjusted to 10-15° Bé., rescreened (200-mesh screen), and pumped to the centrifuge supply tank.

To obtain starch of the desired whiteness, bleaching is performed (after flushing the starch from the second tables) by using a slight excess of sodium hypochlorite at a pH slightly above 8.3 (phenolphthalein). About a 2-hour treatment is required for best results, after which residual chlorine is eliminated with sulfur dioxide, and final adjustment of pH is made. The bleached starch is dewatered by the perforate-basket centrifuge to about 35 per cent water and dried in a vacuum dryer to about 12 per cent water.

Starch in the table tailings and centrifuge overflow water is recovered by two imperforate-basket centrifuges and four cone-bottom settlers (18-hour cycle), respectively. The recovered starch is diluted with clear water to about 4.5° Bé., adjusted to about 9.2 pH with clear saturated lime water, and tabled. This tailing starch, of good quality, is blended with the first table starch and retabled on the second tables. Thus, the factory produces only one grade of starch. Because of insufficient settling and centrifuging capacity, loss of starch (particularly small granules) occurs in the waste water from the tailing settlers and centrifuges and from the tailings resulting from tabling the first and second table tailing starch. With suitable equipment this starch could be recovered.

Starch Factory Control

Mechanical and chemical control was instituted for determining the efficiency of the various factory units, obtaining data for operating statements, and improving efficiency of the process at desired points. Complete small-scale starch manufacturing equipment, which serves for experimental purposes and for testing potatoes by actual extraction and purification of starch, was installed as part of the control and research facilities. The products analyzed and procedures used are as follows:

Potatoes. Analysis of 8-hour composite samples from the washer or grinder hopper suffices for control purposes. In order to determine starch loss during temporary storage of potatoes, samples taken upon delivery to, and removal from, the bins are analyzed for starch, moisture, and solubles, and tare (dirt) is determined on delivery. Numerous weighed samples were placed in bins to obtain the rate of weight loss since in the absence of scales immediately ahead of the grinder, the weight of potatoes ground had to be calculated from the delivery weight by correcting for weight loss and tare. As the starch content of individual potatoes varies considerably, a bushel of potatoes is assembled from random selections, and sections from each potato are mixed to constitute the sample. Sectioning is performed with a motor-driven V-shaped rasp, similar to that used for sampling sugar

beets, with the cut running lengthwise of each half potato. Such a cut yields samples with approximately correct proportions of tissue and starch from each part of the potato.

Pulp. Eight-hour composite samples are collected from the discharge of the pulp press and pulp dryer. Catch samples are taken from the discharge of each mill and at successive stages in the screening system. These products are analyzed for starch and water contents, with the exception of dried pulp, in which water content alone is determined.

Tabling Control. This is conducted by the table operators and involves determination of pH and "density" (best results at 4.5-5.0° Bé.) of starch milk delivered to the tables. Overflow of tailing starch requisite for satisfactory separation amounts to 5 to 7 per cent for each tabling operation. Phenolphthalein (range 8.3-10) and oleo-red B (range 8.6-10.2) are used for pH control by operators; a rather full red with the former and a shade of red approximating its neutral point with the latter are the desired reactions.

Bleaching. A sodium hypochlorite solution (4-6 per cent available chlorine) prepared by absorbing chlorine in sodium hydroxide solution in slight excess of the theoretical proportion is used for bleaching. It is not practicable to add sodium hypochlorite solution in definite proportion to the volume of starch suspension (about 12° Bé.), but rather a sufficient quantity is added to leave a slight excess after treatment for 1 to 2 hours. Operating control is effected by tested qualitatively with potassium iodide solution. Excess available chlorine remaining after completion of bleaching is destroyed with sulfurous acid prepared by absorbing sulfur dioxide from a sulfur burner in water. Potassium iodide solution is used as indicator.

Starch. After being bleached and before going to the dewatering centrifuge, the starch suspension is adjusted to a definite pH value, using hydrochloric acid, or sodium hydroxide, as required. The finished starch is analyzed for water, ash, solubles, viscosity, pH, and color.

Methods of Analysis

Starch. Methods available for determination of starch in sweet potatoes and factory products are not fully satisfactory. Five methods were used: (a) A.O.A.C. official malt diastase method (3); (b) A.O.A.C. official direct acid hydrolysis method (2); (c) magnesium chloride method (13); (d) a rapid method (unpublished) devised by Paine and Kingsbury, which depends on polariscopic determination of degree of conversion by standard amylase (of micro-biological origin) after a definite time at definite concentration, temperature, and pH; (e) a more recent, rapid polariscopic method (unpublished) devised by Balch. Research on these procedures is being continued in the endeavor to develop a satisfactory and rapid control method. Method a has been used exclusively with pulp. Method b, for determining starch in waste waters, yields sufficiently accurate results, since starch sedimented from such wastes contains practically no plant tissues. A comprehensive study of methods for starch determination (5) showed that under certain conditions the standard malt diastase method may fail to yield concordant results in the form usually described.

This is apparently due, in part, to action of malt extract in solubilizing and converting certain nonstarch constituents of the potato. Pretreatment of samples with lime solution corrects this error to a considerable extent.

Moisture is determined by drying definite, convenient weights of material at about 105° C.

Solubles are determined by weighing the residue obtained by evaporating and drying an aliquot of water extract which is prepared by digesting a known weight of material with distilled water and filtering off the insoluble residue; 5-gram samples of potatoes, or 10 grams of starch, are diluted to 500 cc. with water, and aliquots of 50 cc. of potato extract and 100 cc. of starch extract are employed.

Ash (commercial starch only) is determined by incinerating 10 grams of starch.

Color of Starch is determined by a photoelectric-reflectance method, employing the Brice-Keane photometer (15), and is expressed as percentage of the whiteness of a standard plate calibrated with magnesium oxide.

Viscosity of Starch is determined with a Stormer viscosimeter after gelatinizing, under standard conditions, 3 grams (anhydrous basis) of starch, suspended in 10 cc. of cold water, with 100 cc. of water at boiling temperature, and heating in a boiling water bath for definite intervals (25). Measurements are made at 90° C. of the time (in 0.2 second) required for the rotating cylinder to make one hundred revolutions when actuated by a 70-gram weight.

Factory Control Data

Table III presents summarized control data, which include the average (arithmetical) composition of products (A) and factory starch balance (B) for the 1937 season. The average starch content of potatoes (21.05 per cent) was materially lower in 1937 than in 1936 as a result of wet weather at the harvesting period and a freeze at the end of the season. (In 1938 to date of writing, average starch content of potatoes ground was 23.8 per cent, maximum 26.4, minimum 21.7.) The operating data (Table III) show a total extraction of recoverable starch equivalent to 85.8 per cent of the starch in the potatoes, or 10.8 pounds anhydrous starch or 12.3 pounds commercial starch (12 per cent moisture content) per 60-pound bushel, if all starch in the waste waters were recovered and the unaccountable loss disregarded. With a higher content of starch in potatoes, as in 1938 to date, the starch yield would be correspondingly greater.

The large percentage of starch in the waste waters (total accountable loss in Table IIIB) during the 1937 season was due to inadequate recovery facilities. Installation of equipment (centrifuges and settlers) which is planned should result in the recovery of all but a small part of this loss. The solubles content of waste waters is a factor in starch recovery. In the cornstarch industry, solubles are reduced by preliminary steeping of the corn prior to grinding. Steeping, or diffusing, of sweet potatoes has been investigated by Thurber (28) and may have application. A possible solution of the problem of cheap recovery of sweet potato solubles (with simplification of the starch process and recovery of starch from waste waters) is the chemical treatment, pressing, and dehydration

Table III. Summarized Control Data, 1937 Season, Laurel Starch Factory

A. Composition of Products

Product	Starch: Original basis %	Starch: Anhydrous basis %	Solubles: Original basis %	Solubles: Anhydrous basis %	Moisture %	Ash %	Viscosity (Stormer) 0.2 sec.
Potatoes	21.0	66.4	6.84	21.6	68.3	...	.....
Pulp press cake	11.8	47.6	..	..	75.3	...	.....
Dried pulp feed	42.6	47.6	..	..	11.4	...	.....
Commercial starch	..	..	0.2	..	11.2	0.2	110-120[a]

B. Starch Balance

	Weight Lb.	Potatoes %	Starch %
Starch in potatoes[b] entering factory	600,513	21.05	100.00
Starch sacked (anhydrous)	439,608	15.41	73.21
Starch sacked (12% moisture)	499,555	17.51	...
Total losses	160,905	5.64	26.79
Losses:			
Starch left in pulp[c]	76,579	2.68	12.75
Starch in waste waters	75,525	2.65	12.58
Total accountable loss	152,104	5.23	25.33
Total unaccountable loss	8,801	0.41	1.46

a Starch of different viscosities (after gelatinization) was produced for various uses, as required.
b Potatoes ground = 1426.4 tons
c Pulp sacked = 90.78 tons of 11.4% moisture = 6.36% on potatoes.

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of sweet potatoes by a new process for storage (to be described later in this article). In this process a large proportion of the solubles would be separated and recovered without dilution of the juice.

The extent to which it is physically possible and commercially feasible to reduce the starch content of the pulp and increase the percentage of starch recovered has not been finally ascertained. Facilities have not been available for making a comprehensive comparison of the efficiency of saw-blade drum rasps with hammer mills for disintegration of potato tissue and liberation of starch granules. The starch remaining in the pulp has definite value as cattle feed.

Commercial starches always contain inorganic constituents, but it is not fully known to what extent they exist in chemical combination and as contaminants not removed by the purification process. Since the starch granules present an enormous aggregate surface to the liquid phase and possess an electric charge (negative), it is likely that adsorption phenomena occur and may be partly

responsible for retention of inorganic constituents. The lime water process normally yields starch of lower ash content than a simple water extraction and purification. An investigation is being conducted to determine the adsorptive capacity of starches for various inorganic compounds over a range of pH values.

The water content of sweet potato starch stored under atmospheric conditions of southern Mississippi is approximately 12 per cent. This figure has been used in calculating the weight of commercial starch produced instead of basing it on water content at the time of sacking and weighing (which is generally lower), because of the certainty of subsequent absorption of moisture to attain this higher value. The annual production of sweet potato starch by the Laurel factory is shown in Table I.

Properties and Uses

Laboratory studies of the chemical and physical properties of sweet potato starch were made by Thurber (25). Its properties were also studied on the basis of tests in various industries. Coöperative tests were made with southern cotton mills manufacturing sheetings, bag goods, chambray, duck, and denim. In a 4-week comparison test with forty-eight looms, twenty-four used warp yarns sized with sweet potato starch and the other twenty-four employed yarns sized with starch employed previously by the mill. Eighty-five pounds of sweet potato starch were used per slasher batch instead of 110 pounds of starch previously required. The starch content of the finished cloth (same quantities) was approximately the same (7 per cent) in both cases. The looms using yarn sized with sweet potato starch had 244 less stops (caused by knots and broken threads) than the other looms. Other tests showed greater penetration of the warp yarn by sweet potato starch size; the "shedding" of starch from the yarn was thus reduced, and the splicing machines could be operated more efficiently. The characteristics of sweet potato starch for sizing warp yarn thus demonstrated were: smaller proportion required, reduction in number of loom stops, excellent penetration, high increase in breaking strength of yarn, soft "feel" of the goods. Tests in finishing mills showed very clear colors (due to transparency of starch film) when the starch was used in finishing cotton goods after dyeing. About 700,000 pounds of starch produced by the Laurel factory have been used in cotton mills.

The National Bureau of Standards investigated the suitability of sweet potato starch in cotton mills in coöperation with the Textile School of Alabama Polytechnic Institute. The report of this work (24) states that prolonged heating, which is customary in using starch paste as size in cotton mills, caused a decrease in the consistency of all the samples tested (sweet potato and white potato starches), and that the rate of this breakdown varies with individual starches and is quite slow with size made from sweet potato starch. The viscosity of pastes of sweet potato starch produced by the lime water process has the characteristic of generally increasing to a slight extent with time of heating up to 3 or 4 hours. This is an advantage in sizing warp yarn and partly compensates for dilution by condensed steam.

Research has been conducted by Schreiber of the Carbohydrate Research Division, in coöperation with the Textile School and the Chemistry Department of the Alabama Polytechnic Institute and with near-by cotton mills and laundries, on the properties of sweet potato starch in relation to its use by these

industries. The purpose in the case of laundry use was to determine and evaluate the physical properties which it is desirable to attain in starching fabrics in laundries and to obtain a numerical measure of the characteristics of sweet potato starch from this standpoint. This work, the results of which will be published soon, involved the use of physical methods for testing starched materials for stiffness, smoothness, resistance to wrinkling or mussing, starch penetration, stickiness during ironing, and effect of starch films on clearness of colors of laundered fabrics. Testing instruments were developed for, or applied to, the measurement of these properties of starched fabrics. Studies were made of the effect of starches on the wearing life of starched fabrics and on the character and durability of the starch film in them. Sweet potato starch is characterized principally by the clearness of color and the greater smoothness and stiffness of starched fabrics for a given amount of starch used. The observation regarding stiffness coincides with laundry practice in that the proportion of sweet potato starch used is about 20 per cent less than that customarily employed. "Noncongealing" and cold-water-soluble ("colloidizable") sweet potato starches were developed in connection with this work.

The suitability of sweet potato starch for the beater sizing of paper was investigated by the National Bureau of Standards; its report states (33): "Papers sized with sweet potato starch were equal to the best papers sized with the other starches with respect to strength, opacity, and degree of sizing.... Superior retention of mineral filler, and closing the sheet, as indicated by the air permeability, were obtained with the sweet potato starch." Production of adhesives of various types from sweet potato starch was studied by Ward (holder of fellowship contributed to the Carbohydrate Research Division by The Chemical Foundation, Inc.); the results of this work will be published soon. Extensive tests of the suitability of sweet potato starch for the production of adhesives, conducted under the direction of J. E. Clegg, of the Arabol Manufacturing Company, showed (8) that it "can replace cassava starch in every branch of the manufacture of dextrin, vegetable glue, and size." In some cases superior results were obtained. In coöperative tests sweet potato starch dextrin met the specifications of the United States Bureau of Engraving and Printing for postage stamp adhesive. Cassava starch dextrin has been used for this purpose for many years in preference to dextrins made from domestic starches.

Sales of starch by Sweet Potato Growers, Inc., have been principally to southern cotton mills and secondarily to laundries in Mississippi, Alabama, and Louisiana. Recently sales distribution has been extended to the North where, in addition to use in laundries, the starch is also being utilized by bakeries and by confectionery manufacturers in candies of starch "gum" and other types. Sweet potato starch yields a gel of high water content and tender consistency. This property makes it desirable also for use in foods, such as custards and puddings.

By-Products

So far, the best means of utilizing the by-product pulp is as feed. Upon leaving the reel (sixth stage of washing), the pulp (saturated with lime water) is of such consistency, because of the action of calcium hydroxide, as to permit easy dewatering by the roller press to 70-75 per cent moisture. The dewatered pulp dries uniformly in the rotary tubular dryer and retains a desirable consistency (small granular lumps about 1/16 inch in diameter) without the formation

of large lumps. The dried pulp contains about 42.6 per cent starch and 11.4 per cent water (Table IIIA); the average yield is about 6.4 per cent of the weight of potatoes ground.

Cull and surplus sweet potatoes have long been regarded as excellent cattle feed, and it has been stated that they can be substituted successfully for half of the corn in the ration; 3 pounds of sweet potatoes would replace 1 pound of corn.[1] Comprehensive feeding tests on dairy and beef cattle were conducted by the Mississippi Agricultural Experiment Station, using residual pulp from the Laurel factory. Three groups of dairy cows received a concentrate consisting of 100 pounds cottonseed meal, 100 pounds wheat bran, 4 pounds oyster shell flour, and 4 pounds of salt; the groups also received (a) 200 pounds crushed ear corn, (b) 200 pounds dry sweet potato pulp, and (c) 200 pounds dry sugar beet pulp, respectively. The average weight increases per cow per day were 0.27, 0.26, and 0.19 pound with a, b, and c, respectively (20). Crushed ear corn and sugar beet pulp had about the same value for milk and fat production and sweet potato pulp was approximately 95 percent as valuable; the latter appeared to be as palatable to dairy cattle as crushed ear corn and maintained the weight of the animals satisfactorily. The report of the tests states that "this pulp probably more nearly resembles corn in composition than it does any other of our common grains and, as the yield of corn is usually low and the cost of production high, it is desirable to find some concentrate that may be used as a substitute."

A 104-day feeding test on beef cattle was conducted by the Mississippi Agricultural Experiment Station (19). Four groups, each consisting of eight Hereford steers, were fed, respectively, per steer per day: (a) 6.8 pounds cottonseed meal, 64.4 sorghum silage, 2.9 Johnson grass hay; (b) 2.5 pounds cottonseed meal, 13.4 sweet potato pulp, 30.1 sorghum silage, 2.5 Johnson grass hay; (c) 2.5 pounds cottonseed meal, 16.0 corn and cob meal, 59.9 sorghum silage, 2.3 Johnson grass hay; (d) 6.8 pounds cottonseed meal, 15.3 sweet potato pulp (ad libitum), 3.0 Johnson grass hay. The steers in group d "made considerably greater daily gains, cheaper gains, shrank less, and had a higher dressing percentage than the steers in the other three lots. The selling price per 100 pounds was also in favor of this lot." The selling price per 100 pounds and cost per 100-pound gain for each of these lots of steers were, respectively: (a) $11.25, $17.22; (b) $11.00, $18.91; (c) $11.50, $20.06; (d) $11.90, $15.32. The selling prices are those obtained simultaneously at the National Stockyards, St. Louis, Mo., where the thirty-two steers were marketed. Sweet potato pulp was the only feed that reduced the requirement of silage in the ration.

Experience in sale of the pulp by Sweet Potato Growers, Inc., indicates that this feed could play an important part in the dairy industry of the South, which in general has not been overdeveloped. The following statement (6) by Black and McComas (Beef and Dual Purpose Cattle Investigations, United States Bureau of Animal Industry) regarding the possible value of sweet potato pulp for feeding beef cattle in the South is of interest:

The cattle population of the seven Coastal Plain States from North Carolina to Louisiana is approximately 9 per cent of the total cattle population of the United States. If Texas were included, the percentage would be more than

1 From replies to questionnaire addressed to southern agricultural experiment stations.

doubled. The almost complete elimination of the cattle tick in this area and the programs for adjusting cotton, corn, peanut, and tobacco acreages and conserving soil resources should result in an appreciable increase in the number and quality of the cattle in the Coastal Plain States, where the by-product pulp from sweet potato starch would be principally available.

Observations of animal husbandry agents in these states and the data on the cattle population for the past ten years amply support this prediction of the increasing importance of cattle on the farms and open range of this area. The cattle population in these states has increased considerably during the past six years and is now greater than at any time in the past ten years. There is so much land that is no longer fit for cultivation and so much that must be put into grass if any appreciable fraction of its agricultural value is to be maintained, that cattle are almost certain to become of increasing importance in the Piedmont section, which lies adjacent to the Coastal Plain.

Even with the present cattle population, fattening feeds such as corn are considerably higher in price than in any other part of the United States, excepting possibly the North Atlantic States. The Coastal Plain States are notably deficient in supplies of fattening feeds, and corn yields are much lower than in other corn-growing sections. Any appreciable increase of cattle is certain to increase the demand for fattening feeds since it is not practical on account of comparatively high freight rates to ship feeder cattle from the Southeast to areas in the North where feed is much cheaper. Hence the logical procedure is to provide additional fattening feeds in the Coastal Plain States in order that the local demands for beef may be supplied and the surplus, if any, shipped northeastward to such markets as Richmond, Baltimore, Philadelphia, and Jersey City. As transportation costs promise to remain relatively high and diversified farming tends to increase throughout the country, there seems to be ample justification for plans that would tend to make the Southeast somewhat less dependent on other sections of the country for its meat supply.

Sweet potato pulp supplements cottonseed meal in the ration through the addition of carbohydrates. It renders more effective the utilization of this southern feedstuff which, because of local availability and lack of sufficient carbohydrate feed, is often fed as the principal concentrate in a cattle ration. Sweet potatoes contain a substantial proportion of vitamin A precursor and also vitamins B (old terminology) and C (14); the amounts of these vitamins remaining in sweet potato pulp have not been determined, but research on this subject is planned. The dried pulp of the Laurel factory has been sold principally to dairymen in southern Mississippi. It has found a ready market; the price received by Sweet Potato Growers, Inc., for the 1937 season was $27.00 per ton.

Storage of Sweet Potatoes and Period of Operation of a Starch Factory

Using fresh potatoes, the Laurel factory can operate only about 100 days per year (24 hours per day and 7 days per week)--say from September 1 to December 15. It is desirable that operation be possible throughout the year, with resulting distribution of fixed charges over a greater volume of products. With year-round operation, the factory could produce three and a half times as much starch annually with practically the same capital investment for buildings and equipment.

Sweet potatoes are susceptible to action of molds and other forms of rotting and do not store well. Attempts to devise means of keeping sweet potatoes by controlling atmospheric temperature and humidity in the storage space were unsuccessful, particularly when the potatoes had been bruised. Furthermore, the sweet potato is rich in amylase and considerable conversion of starch occurs during storage, even at optimum temperature and humidity. The usual curing process is not feasible for preparing potatoes for storage for starch manufacture. Dehydration of sliced or ground sweet potatoes by ordinary heat application methods is not practicable because of cost and necessity (to prevent gelatinization of starch) of using, during the initial stage, a relatively low temperature range which would permit some conversion of starch by the amylase contained in the potato.

However, research by Hopkins and Phillips, holders of fellowships contributed to the Carbohydrate Research Division by The Chemical Foundation, Inc., is promising for accomplishing the drying of sweet potatoes for storage at sufficiently low cost. They found (12) that, when sweet potatoes are ground or sliced and treated with certain vapor or liquid reagents (principally fat solvents), the cell walls become very permeable to liquid so that a large proportion of the juice can be pressed out by mechanical means, which is cheaper than fuel. Removing juice in this manner (public service patent application pending) instead of evaporating water makes possible the recovery of a large proportion of solubles without dilution. Among reagents which gave the best results are carbon tetrachloride and carbon disulfide. Satisfactory results were obtained with sulfur dioxide. The proportion of reagent required is very small.

On a laboratory scale 60 to 70 per cent of the juice in sweet potatoes was removed by chemical treatment and pressing; only about one-tenth as much juice was removed at the same pressure from potatoes not so treated. Much of the remaining water which must be eliminated in order to reduce the water content to about 12 per cent (at which the potatoes are stable for storage) can be evaporated by using starch factory chimney gas. The by-product value of the undiluted juice, in conjunction with the use of factory flue gas, should make possible a low net dehydration cost. The chemical treatment and pressing procedure has the advantage of being an atmospheric temperature process; conversion of starch by amylase, or otherwise, was practically nil. Subsequently an important improvement in the process was made by using a very small proportion of dry hydrated lime (public service patent application pending).

The solids content of juice thus expressed from sweet potatoes is 9.5 to 11.5 per cent, of which 6.5 to 8.5 per cent consists of sugars (principally sucrose in freshly dug potatoes). There are various possibilities of utilizing the juice, including fermentations of certain types or concentration (in a multiple-effect evaporator) to molasses density and mixing with the residual pulp to increase yield of by-product feed. Elimination of solubles at this stage will permit simplification of the starch process with some reduction in manufacturing cost. A pilot plant for working out operating details and mechanizing the continuous dehydration of sweet potatoes is being erected at the Laurel factory.

Considering the temperatures prevailing in the South, particularly during summer and early autumn, operation of a sweet potato starch factory throughout the year would necessitate microbiological control for holding in check various

microörganisms which could be very detrimental, even to the point of stopping factory operation. Research on this subject was conducted during the 1938 season in coöperation with Hall and McFarlane, of the Food Research Division, Bureau of Chemistry and Soils, and a cheap process of microbiological control was devised which has proved effective. Results of this investigation will be published later.

The dehydration method mentioned might assist in solving the problem of utilizing cull and seasonal white potato surpluses. Except in a few sections, it has not been possible to develop means of utilization because of the annual variation in quantity available, together with the fact that such culls and surplus are scattered over a wide area and are not usually available in any one locality in sufficient quantity to justify the capital investment in a factory to utilize them. If this method of dehydration can be developed on a sufficient-cheap basis, it might be feasible to dry surpluses at various locations in production areas and then, since the dry weight is about one-third of the original weight, to collect them at central points for utilization (possibly under refining-in-transit freight rate).

Additional Products Made Possible by Dehydration

Development of the dehydration process will make possible an increase in direct products from sweet potatoes and in by-products from starch manufacture. The possibility of dehydrating sweet potatoes cheaply in the manner described and also of eliminating a large proportion of solubles has suggested the idea of grinding these dried potatoes to a flour, of dry refining the flour, and of using it for a variety of purposes, depending essentially on the starch content (public service patent application pending). The particles of skin and fiber in sweet potato flour are harder than the starch granules, and it is possible by a simple dry-refining process (grinding and sieving) to eliminate a large proportion of such material from the flour. Since the pigments in sweet potatoes are associated largely with the skin and fiber, most of which is thus eliminated, refining results in flour of a much higher starch content and lighter color. The screen tailings can be mixed with the by-product pulp from the starch factory for use as cattle feed at a value of about 1 1/3 cent per pound. Addition of juice extracted by the dehydration process and concentrated to molasses density would serve to incorporate and hold such screen tailings in the by-product feed. Investigations by Paine and Kingsbury (to be published) resulted in the production of flours of very light color containing 80 to 90 per cent of starch on a dry basis. There is a definite possibility that such flour can be bleached white by dry processes similar to those used for bleaching wheat flour. It should be possible, by dehydrating sweet potatoes as described and then grinding and dry refining and dry bleaching, to produce flour of practically any grade desired at a low cost.

An investigation (results to be published) has been conducted by Paine and Ward on the production of adhesives from such flour (21), with the thought that adhesives suitable for use in the manufacture of cartons, corrugated fiber boxes, and similar shipping containers, and possibly for the wood veneer and plywood industry, might be developed from flour of highest grade. Such flour would have the advantage of low cost; adhesives made from it possess some color which, however, may not be objectionable for certain purposes. Glues equal in

adhesive quality to those made from cassava starch were obtained from high-grade sweet potato flour produced as indicated; some difficulty has been experienced in applying these glues with applicators now used; the subject is being further investigated, including the design of different type of applicator.

Research attention has been given to the possible use of sweet potato flour as a malt adjunct in the brewing industry--i.e., for providing starch to be converted by malt into fermentable sugars and also furnishing solids which contribute to the body of beer and ale. Tests were made at first with sirup prepared by Paine and Yanovsky from sweet potatoes (22). A satisfactory yield of brewing sirup was obtained by converting ground (unpeeled) sweet potatoes with acid (low-concentration) under pressure. Brewing tests with both sirup and flour, in mixture with other brewing materials, yielded beer with satisfactory flavor and other acceptable characteristics. Because of lower cost, the flour would be preferable to sirup for such use. There is a possibility of using sweet potato flour of certain grades in baking (17), particularly if a considerable proportion of amylase, so abundant in sweet potatoes (10), can be retained unimpaired. Tests to date show promising results, but are not yet conclusive and are being continued. Efforts to utilize sweet potato flour will assume increased importance in proportion to the success of efforts which are now being made to reduce unit cost of growing sweet potatoes, as shown in the following section.

Agricultural Aspects

As in many industries, raw material cost is greater than processing cost in sweet potato starch production, and agricultural problems have required particular attention. Since this enterprise involves utilization different from that considered heretofore in agronomic and plant physiological research relating to this crop, systematic experimentation from a new viewpoint was undertaken by Anderson (1) of the Mississippi Agricultural Experiment Station. Field experiments were started with reference to related agricultural problems such as influence of composition and amount of fertilizer on yield and starch content of sweet potatoes, influence of various factors on rate of starch storage by sweet potatoes, and comparative testing of different varieties with respect to starch yield per acre and related cultural characteristics. This research (still under way) has been conducted each season (beginning in 1934) on selected plots in the Laurel, Miss., section.

Although sweet potatoes are the largest vegetable crop in the South, they have been grown principally on a small-plot basis. Large tonnage per acre has not been consistently obtained; average yield per acre in the United States was 78 bushels in 1936 (31). Low yields have been due partly to the growing of lower yielding varieties of sweet potatoes of smaller size on much of the acreage planted in order to meet market requirements, and partly to the fact that many growers have sought to obtain early maturity and early harvesting in order to take advantage of better market prices. The grower has endeavored to obtain as high a proportion as possible of potatoes of U. S. No. 1 grade (a medium size potato of rather uniform shape) for the food market.

A high yield per acre of sweet potatoes of high starch content is necessary for starch production in order that they may be sold at a price remunerative to both factory and grower. The success of the latter is measured by the quantity of starch produced per acre, a factor not heretofore considered by plant breeders

and physiologists. It was early recognized in this enterprise that several conditions observed in growing sweet potatoes for the food market must be altered. Plantings are now made as early as possible so as to obtain a long growing season. In the Laurel section, growers often desire to plant potatoes in the same ground after harvesting truck crops. This is not always feasible, but with crops such as spinach sufficiently early plantings (first 10 days in May) may be made after harvesting the truck crop. The quantity of fertilizer has been increased to 600-1000 pounds (6-8-6 and 6-8-8 composition) per acre. Yields of 300-400 bushels per acre are frequently obtained, and yields up to 500-600 bushels have been reached. Experience in this section indicates that, by following recently established practices, yields of at least 300 bushels per acre should be the rule, with few exceptions.

The United States Bureau of Plant Industry and the Mississippi and Louisiana Agricultural Experiment Stations are investigating the development of sweet potato strains of still higher starch content or otherwise greater suitability. Miller, of the Louisiana Agricultural Experiment Station, has obtained seed from sweet potatoes under Louisiana conditions and has produced a great number of seedlings in crossbreeding experiments. The Bureau of Plant Industry has grown some thousands of seedlings from seeds obtained through cooperation with the Puerto Rican, Hawaiian, and one of the Cuban agricultural experiment stations. This is an important development in breeding research for this crop. An investigation of great potential value is being conducted by Boswell, Steinbauer, and Hoffman, of the Bureau of Plant Industry, and Edmond, of the South Carolina Agricultural Experiment Station, on the cause of the "barren hills" observed in sweet potato fields. These hills, almost devoid of potatoes, may occur alongside hills with abundant yield. Solution of this problem is an important factor in increasing further the acre yield. Investigations by the Bureau of Plant Industry and southern agricultural experiment stations to improve sweet potato propagation and culture are in progress.

Table IV shows the average yield per acre and starch content of ten leading varieties grown in test plot experiments by Anderson, of the Mississippi Agricultural Experiment Station, at Laurel in 1936. Most of the potatoes used at the Laurel factory consist of the two Mississippi Triumphs, with the trend toward the Blue Stem strain which has given consistently higher yields.

Table IV. Average Yield and Starch Content of Sweet Potatoes

Variety	Acre Yield Bushels	Starch Content %
Mississippi Blue Stem Triumph	308	24
Wennop (from Australia)	303	27
Pierson	293	26
U. S. 95984	279	21
Mississippi Green Stem Triumph	275	25
U. S. 85985	275	21
Norton	267	28
Nancy Hall	252	22
Puerto Rico	244	21
Southern Queen	212	23

Because of its small plot basis, the sweet potato crop has not been mechanized to nearly the same extent as cotton, corn, and wheat. Improvement in agricultural implements is necessary for developing the crop on a more intensive basis in larger plots. Industrial utilization of sweet potatoes will result in growing the crop in large plots and thus make possible the use of more efficient implements for planting and harvesting; this, in turn, will result in lower production cost. Research for developing a more efficient digger was conducted by Jones of the Mississippi Agricultural Experiment Station and by Gray, Hurst, and Randolph of the United States Bureau of Agricultural Engineering during the 1937 and 1938 seasons. In 1938 Randolph made important progress in adapting the combination digger and loader, used for white potatoes, to the harvesting of sweet potatoes in large plots. Improvement in present machines for setting potato plants will be undertaken. Such mechanization of this crop has been impracticable heretofore because of the need to avoid bruising the potatoes in harvesting (potatoes heal cuts but not bruises). For industrial utilization, bruising is not so important since the potatoes will be processed for starch or dehydrated for flour or storage within a short period.

Harvesting and utilization of sweet potato vines would be feasible on large plots; preliminary removal of vines (often of luxuriant growth) by a suitable mechanical cutter and rake (now being investigated) would expedite the operation of a combination potato digger and loader. Sweet potato vines have good feeding value and are palatable to cattle. The South Carolina Agricultural Experiment Station found the protein, fat, and fiber contents of sweet potato vines on a dry basis to be about 12.5, 4.9, and 18.2 per cent, respectively, compared with an average of 16.8, 3.8, and 26.8 per cent, respectively, for red clover, crimson clover, cowpea, and soybean hays (16). Production of 0.5 to 2.0 tons of sweet potato vine hay per acre might be possible. After being cured, the vines might be chopped and fed as such or mixed with the dried by-product pulp from the starch factory. Possibly the vines might be siloed (most conveniently in trench silos near the sweet potato fields). These possibilities are being investigated. Use of vines as feed (preferably with application of the resulting manure to the soil at a suitable stage in crop rotation) in conjunction with the by-product recovery procedures in starch manufacture, would accomplish practically complete utilization of the sweet potato crop.

Starch production at the Laurel factory has increased steadily from year to year. However, time has been required to improve agricultural practices (according to the new viewpoint indicated) and to demonstrate to farmers that acre yield of sweet potatoes can be increased to such an extent as to make the crop profitable to them at a price that the factory can afford to pay. The membership of Sweet Potato Growers, Inc., increased from about four hundred in 1934 to almost thirteen hundred in 1938. It is estimated that in 1938 over 200,000 bushels of sweet potatoes were produced under contract (an amount equal to maximum factory capacity). In 1937 the Agricultural Adjustment Administration added a crop diversion payment of 10 cents per bushel to the price of 20 cents per bushel paid by Sweet Potato Growers, Inc., for sweet potatoes (field run), a total of 30 cents. With development of this industry it is logical to expect that sweet potatoes for starch production will be bought on a basis of starch content (similar to purchase of sugar beets on a basis of sucrose content).

The sweet potato is in the front rank among plants as a starch producer. At a yield of 400 bushels per acre and 25 per cent starch content, 3 tons of starch are produced per acre. If alcohol from agricultural products is ever used

in motor fuel in the United States, the sweet potato is eminently suitable as raw material, and much of the present research will be equally applicable to alcohol production. The research here reported has already stimulated interest in Italy along similar lines (23). Data available from several years of recent experience indicate that, by selecting suitable soil and by following approved practice, the cost of producing sweet potatoes can be materially reduced, particularly if they are grown in large plots and handled by properly mechanized methods. A factory producing 15 tons of starch per 24-hour day at a recovery of 12.5 pounds of commercial starch per bushel of sweet potatoes would require 240,000 bushels per 100-day season. At an average yield of 200 bushels per acre, 1200 acres would be required. Sweet potatoes are hauled to the Laurel factory an average distance of about 10 miles, up to a maximum of 35 miles. Within a radius of 25 miles it should easily be possible to produce 1,000,000 bushels of potatoes annually.

Requirements for a Factory with a Capacity of 15 Tons Starch Daily

Water and Chemicals Consumption. The following discussion refers to a factory with a capacity of 15 tons of starch per 24-hour day (50 per cent greater than that of the Laurel factory). Water consumption is shown in Table V. Water should not contain an excessive quantity of dissolved solids or more than 1 p.p.m. of iron. Consumption of chemicals is shown in Table VI.

Table V. Approximate Water Requirements for Manufacture of Sweet Potato Starch

	Ratio Water:Potatoes	Gal./Ton Potatoes
Lime water:		
Grinding and screening system	2.5- 3.0	600- 720
Starch purification system	0.2- 0.4	48- 96
Fresh water:		
Potato washing and pump priming	3.0- 5.0	720-1,200
Starch purification system	3.0- 3.5	720- 840
Starch drying system, vacuum (this water is recirculated)	0.5- 1.0	120- 240
Boiler (hot water returned to boiler)	0.3- 0.5[a]	72- 120[a]
Miscellaneous (exptl. starch plant, laboratory, cleaning, etc.)	0.5- 0.6	120- 144
Total	10.0-14.0	2,400-3,360

a If steam power is used, these figures will be exceeded.

Table VI. Approximate Consumption of Chemicals for Manufacture of Sweet Potato Starch

	% on Potatoes	Lb./Ton Potatoes
Lime (process water)	1.5 -2.0	30 -40
Chlorine	0.008-0.012	0.16- 0.24
Sodium hydroxide	0.010-0.015	0.20- 0.30
Sulfur	0.008-0.010	0.16- 0.20
Hydrochloric acid	0.05 -0.08	1.0 - 1.6

Part of the calcium hydroxide used at the Laurel factory is lost in settling basins as calcium carbonate by reaction with soluble carbonates and carbon dioxide remaining in the water after aeration. Water of low carbon dioxide or carbonate content would permit a material saving in lime. Hydrated lime of high grade should be used. The quantity of chlorine and sodium hydroxide varies with the degree of bleaching required, which is dependent upon efficiency of purification of the starch prior to treatment with sodium hypochlorite. Some sodium hydroxide is used in the water purification system for removal of iron by sodium hydroxide treatment and sand filtration. Consumption of sulfur dioxide for reducing residual sodium hypochlorite after bleaching does not vary much. The starch is alkaline when bleached, by virtue of a small amount of residual lime water and the sodium hypochlorite. The quantity of acid (hydrochloric) required for final adjustment of pH varies somewhat with the alkalinity of the bleached starch and the pH desired.

Potato Bins, Flume, and Washer. Potatoes are delivered promptly after digging. A 3 to 5 day reserve supply is required for periods of inadequate delivery (Sundays and rainy weather). Ventilated wooden storage bins 5 feet deep, with width dependent on construction (flat or sloping bottom and location on each side of, or directly over, a flume) are satisfactory; bins should have a roof about 10 feet above the floor. In most locations it would not be feasible to store potatoes in bins elevated above wagon height.

Fluming is an economical method of transporting potatoes from bins to factory. Concrete flumes 12 inches wide and 24 inches deep, with slope of 1 foot per 100 feet in straight portions and 1.25 feet per 100 feet in curves, used at the Laurel factory, are ample. (Ten to twelve pounds of potatoes, 12 inches or greater in diameter, have been delivered.) A pit separated by a series of iron gratings placed so as to deflect potatoes and permit settling of stones and sand into the pit should be built beneath the main flume a short distance ahead of the elevator leading to the washer. Sticks, leaves, etc., may be removed by iron hooks projecting into the flume water or by automatic trash collectors (as in the beet sugar industry). Factory waste water (e.g., from starch dewatering centrifuges, condenser water, or potato washer overflow) may be used for fluming.

If the potatoes are grown in light soil, fluming water can be recirculated to a considerable extent, waste water being added continuously, with the excess overflowing to the sewer. The quantity circulated is about 300 gallons per minute. Potatoes may be elevated from flume to washer by a wheel, paddles, scroll, or drag slat elevator. A paddle washer similar to that used for sugar beets is suitable; or if potatoes are grown in light soils and are easily cleaned, a screen washer is satisfactory. If justified by scale of operation, incoming potatoes should be weighed after washing so as to permit an accurate starch control balance. In such case, the potatoes are elevated to a scale discharging into the grinder hopper.

Grinding Equipment. Starch is stored in sweet potatoes in sacs containing a large number of granules, and these sacs should be ruptured with as little disintegration of other tissue as possible. Swing hammer mills have given good service at the Laurel factory. Drum rasps require less power at equal grinding rate, but initial cost is greater and there is more expense to keep them in condition than with hammer mills of the same capacity. Too fine grinding in the

second mill produces a pulp which is difficult to handle in later stages of the process; screens with 1/8-inch and 1/64-inch openings for the first and second hammer mills, respectively, gave good results. A suitable first hammer mill with a capacity of about 4 tons of potatoes per hour has the following characteristics: number of hammers, twenty-four; width of hammers, 1.5 inches; thickness of hammers, 0.5 inch; diameter of cylinder with hammers extended, 27 inches; width of throat, 14 inches; speed, 2000 r.p.m. The second hammer mill is identical, except that it has forty-eight hammers of 1/8-inch thickness.

The first grinder should be provided with a device to ensure positive feed of potatoes and with water lines for introducing fresh lime water and countercurrent water from the screening system. Because of the large size of the potatoes now grown, a cutting station ahead of the first mill would be advantageous for obtaining more uniform feed and greater grinding capacity. It has not yet been possible to make a thorough comparison of efficiency, in relation to cost, upkeep, and power consumption, of all other possibly suitable mills, such as attrition and cage mills and those used for preparing paper stock.

Starch Separating Equipment. The essential factors in extraction of starch from sweet potatoes are: (a) rupture of the sacs containing starch granules, which is accomplished by milling and, to an appreciable extent, by continued agitation of the pulp; (b) flotation of liberated starch granules from fibrous and cellular material by means of water and screening. Ratio of water to pulp, physical condition and rate of flow of pulp, size of screen openings, and type of screen play a part in this operation. The jig or shaker screen used in the cornstarch industry is satisfactory and economical to construct. The screen is applied direct to the framework (well-braced wood construction) by tacking (but protected from the wooden edges by tape), or the screens are made in separate panels inserted in the framework. The spacing of the five to seven agitator pockets crosswise of the framework, which are desirable for obtaining an even flow of pulp down the screen, is dependent on the screen width. The framework should be provided with a headboard (for wire screens), on the same plane as the screens, to take the load of the stream of pulp from the distributors off the screen, and with a tailboard for discharge.

The screen frame may be mounted by an overhead rod, springwood suspension, or metal bearing supports of various types. Less power is required for the first two mountings, but they are less advantageous as to construction cost and facility of cleaning and changing screens. Well-constructed eccentric drives are important from the standpoint of power consumption and upkeep. Tests with brushing screens (widely used in the European white potato starch industry) gave unsatisfactory results; action of the brushes liberated latex adhering to and incorporated in the potato tissue, and caused it to coat the screen surfaces and become dispersed in the starch milk. Reels or rotating screens (circular or hexagonal) might give good service, possibly in later positions, but would be difficult to clean.

Arrangement of screens should be such that the starch milk and pulp tailing from the screens can be collected separately or appropriately combined in a countercurrent washing system. Since sweet potato pulp does not flow readily, the tail ends of the screens should be located over receiving tanks so as to permit a vertical drop; otherwise, a conveyor must be used. Intermediate agitation is required for highest extraction, and it is not desirable to arrange the

screens in cascade fashion--i.e., to allow the pulp to fall by gravity to successive screens, with little agitation between screens.

Because of difficulty with which the pulp flows and the tendency to clog pipe lines behind partially closed valves, it is important in feeding a screen system to use a header with individual distributor lines (1 1/4-inch pipe with at least a 3-foot vertical drop from the header) leading to each screen. A horizontal section can be inserted between the vertical section and distributor. The valve, which is left practically open under normal operating conditions, is placed about midway of the vertical section. Screens of No. 5XX or 7XX silk for pulp (No. 3XX for the first position), and of 150-mesh for crude starch milk and 200-mesh for tabled starch milk are satisfactory.

Starch Purification Equipment. Because of the highly pigmented liquid obtained and the high proportion of solubles in the sweet potato, the starch is subjected to two tabling operations, plus a final wash to obtain the desired degree of purity. (By using the dehydration process previously mentioned, it may be possible to eliminate one tabling operation.) The equipment required consists of starch settling tables with auxiliary tanks, pumps, distributing system for starch milk and tailings, and flushing system for removing starch from the tables. In constructing tables, a smooth surface is necessary to prevent depressions in sedimented starch in which impurities may accumulate. Wooden tables may be used and are more easily releveled than concrete tables. The table area required for two tablings and for purification of starch from the first and second table tailings is 550-600 square feet per ton of finished starch per day (forty-five tables, 24 inches x 100 feet, for a factory producing 15 tons of starch daily).

For obtaining an even feed, a constant head of starch milk is circulated through a header line distributing to the various tables. The feed line consists of a 3/4-inch pipe extending vertically at least 3 feet from the header to a few inches above the table floor at the table head, with a quick-opening valve close to the header. The flow of starch milk (4.5° to 5.0° Bé) under normal conditions is 3 to 5 gallons per minute. A flushing system (pump capacity of 750 gallons per minute at 30-foot head required for flushing two tables simultaneously) is desirable for eroding the settled starch (about 50 per cent water content) from the tables by rapidly circulating over them a large volume of water, or starch suspension, in a closed system. The 10-15 per cent of starch which is tailed off in two tablings is recovered by settling or centrifuging, followed by tabling (after rescreening). No difficulty from accumulation of impurities and fine starch has been encountered in returning this tailing starch to the process before the first or second tabling operation.

Starch Dehydrating Equipment. Continuous vacuum filters can be used for the first step in dehydration; they require less labor for operation but do not remove as much water from the starch as centrifuges. When extra washing of the starch is desired, as at the Laurel factory, by dewatering from a 10-12° Bé. rather than a 20° Bé. suspension, which is necessary for continuous filter operation, this can be accomplished by centrifuging or by using a blanket wash on a drum type filter. The capacity of the 40-inch centrifuge used is 400-450 pounds of dry starch per charge, or 1200-1500 pounds per hour, depending on the density of starch milk and the ease of dewatering the charge.

Dryers of several types are suitable for the final step in dehydrating starch. Continuous operation is preferable to the batch system, which is ordinarily required in vacuum-drying installations. Kiln dryers are less expensive to install but, unless suitably mechanized, may require excessive labor. Vertical turbine tray dryers afford continuous operation and should give satisfactory results. The quantity of water to be evaporated per ton of dry starch (12 per cent moisture) ranges from 700 to 1200 pounds, depending on moisture content (35 to 45 per cent) of the centrifuged or filtered starch delivered to the dryer.

Since it is difficult in tabling and centrifuging operations to displace completely the "fruit water" in which the first settling of starch occurs, it is important to dewater as efficiently as possible, not only for reducing water content so as to obtain greater starch dryer capacity but also for starch purification. Under well-controlled conditions, no difficulty due to gelatinization occurs with a vacuum starch dryer; but when proper operating conditions are not maintained, such as control of vacuum, temperature, maximum moisture content of wet starch, and temperature of the inner shell of the dryer while being filled (especially when solubles content is excessive), difficulty may be experienced in drying the starch without the formation of numerous small, hard lumps which required pulverizing.

Handling of Finished Starch. Sweet potato starch may be produced in either "pearl" or powdered form; the latter is the only form produced by the Laurel factory. A starch mill with bolting reel and auxiliary standard equipment (starch scrolls, elevators, and dust collectors) should be provided. As in other starch industries, blending hoppers (capacity, 50,000-100,000 pounds of starch, are useful for obtaining a uniform product, packing equipment being fed directly from them. Containers vary with the trade served--i.e., cotton sacks for cotton mills, barrels for laundries, and paper sacks for paper mills. A warehouse, 100 x 200 feet, is required for storing 100-day production (about 1500 tons starch and 500 tons dried pulp). Under some conditions starch dust is highly explosive; explosions, such as have caused loss of lives and property, can be avoided by observing safety codes (32) developed during recent years.

Pulp Handling Equipment. Pulp from the screening system can be dewatered by continuous roller presses of the type used for brewery and distillery spent grains, provided calcium hydroxide is used and the screens are sufficiently fine to prevent packing with pulp. The water content of the pulp can be reduced from 94-95 to 70-75 per cent (corresponding to 81-85 per cent extraction of water) by such presses. It has not been possible to determine the relative efficiencies of water expellers and presses of all the different types which might be suitable for this material. From 4200 to 5200 pounds of water (equivalent to 245-335 pounds per ton of potatoes processed) must be evaporated for each ton of dry pulp produced. At a grinding rate of 4 tons per hour, a dryer capable of evaporating up to 1400 pounds of water per hour is required. Pulp treated with calcium hydroxide dries rapidly. Since it is not essential to prevent gelatinization of starch in the pulp, atmospheric steam-tube or direct-fire rotary dryers can be used.

Miscellaneous Equipment. Considerable pumping is required, and either piston or centrifugal pumps may be used. The latter should have open impellers so that they will not become easily clogged. Whenever possible, such pumps should

be installed so as to be self-priming, since the semifluid pulp is not easily picked up. To prevent rapid wearing of packing, slow to medium speed pumps (not over 1800 r.p.m.) should be used for pumping starch milk and pulp. Except in isolated positions, belt-driven pumps actuated from line shafts are preferable because of simplicity and less danger of getting out of order. Many of the pumps must be mounted in positions where they may become wet, and for such service individual motor-driven pumps are subject to damage. Pumps with characteristics similar to those used for handling paper stock can be used for some services, but the water-fiber ratio is greater in paper pulp than in sweet potato pulp.

Painted steel tanks are used at the Laurel factory. Wooden tanks for holding starch milk and pulp at various steps in the process have lower initial cost and can be utilized. Concrete tanks are suitable for some purposes, such as preparation of lime water and sodium hypochlorite solutions, and for settling factory waste waters for final recovery of starch. All tanks for holding starch milk and for holding pulp at intermediate steps in the screening system must be equipped with agitators. Since thorough agitation of the pulp is a factor in starch extraction, agitators in pulp tanks should be operated at rather high speeds (greater than for simply mixing screened pulp and countercurrent water). Agitators in starch milk tanks should operate at low speeds and have a wide sweep; they should be so constructed that, when not operating, the blades may be raised to prevent "freezing" due to starch settling.

Because of the alkaline process, steel pipe lines can be used for conducting starch milk, pulp, and water. When gravity flow is feasible, wooden troughs are suitable and cheaper to install. Rubber hose is satisfactory for transporting sulfur dioxide and sodium hypochlorite solutions.

Heat and Power. Selection of power source depends on relative installation operation, and maintenance costs. If coal, gas, or oil is sufficiently cheap, steam engines are preferred with use of exhaust steam for drying and heating. If electricity is not too expensive, electric motors may be used, and only a small steam-generating unit for providing heat for the dryers would be needed. Wherever practicable, line-shaft power transmissions are preferable to individual drives because of the saving in operating cost. For drying operations (starch and pulp) a boiler capacity of 1.75 to 2 h.p. per ton of potatoes per day is necessary; required factory motive power is 2 to 5 h.p. per ton of potatoes processed and varies with a number of factors--e.g., proportion of hand labor and type of equipment.

Labor Requirements. Table VII shows estimated labor requirements based on 1937 operation of the Laurel factory. With increase in scale of operation, man-hours per ton of starch produced can be greatly decreased. Fifteen tons of starch per 24-hour day are regarded as the minimum practicable capacity for a factory using the present procedure (research is being conducted on procedures suitable for smaller factories, 29); a capacity several times greater is desirable (and practicable in every way) in order to reduce fixed charges and labor cost per unit of starch produced. On a considerably larger scale of operation the over-all manufacturing cost (exclusive of raw material cost) might be reduced to 0.75 cent per pound of starch, as compared with about 1 cent per pound for a factory of the size of that at Laurel. Operation throughout the year would also reduce this cost item.

Table VII. Management and Labor Requirements for Sweet Potato Starch Factory Producing 15 Tons of Starch per day (Three 8-Hour Shifts Daily)

		No. Men	Hours per Day	Av. Daily Man-Hours
Management	Manager	1	..	..
	Stenographer and bookkeeper	1	8	8
	Fieldman	1	8	8
Skilled labor	Night superintendent	1	8-12	10
	Day foreman	2	8	16
	Chemist	1	8-12	10
	Machinist and electrician	1	8-12	10
Unskilled labor	Lime water, water treatment, preparation of chem. solns.	2	8	16
	Flume	3	8	24
	Washer and grinder	3	8	24
	Screening system	6	8	48
	Tables	3	8	24
	Tailing settlers	3	8	24
	Centrifuges	3	8	24
	Starch dryer and boiler	3-6	8	24-48
	Starch packing	2	8	16
	Pulp drying and packing	3	8	24
	Pulp and starch storage	2	8	16
	Watchmen	3	8	24
	Janitor	1	8	8

Total, 342 man-hours per day (exclusive of management)
Approx. starch production, 87.7 lb. per man-hour

The factory plan can be varied--for instance, in order to adapt the equipment to an existing building. If desired, the grinders could be located on an upper floor and the washed potatoes elevated to them rather than pumping the ground potatoes up to the first set of screens. For compactness the dry kilns (or vertical, turbine tray dryer) in the plans are placed inside the main building. They could also be placed in a separate building. In the location indicated, considerable ventilation is required to conduct off moisture-saturated air. Also, if the kilns are placed as indicated, the construction between kilns and tables above must be made waterproof to prevent damage to starch by water leakage from the tables and must be insulated to prevent the tables from being warmed to a point where microorganism growth is excessive. In large factories a separate building is desirable, not only for the starch dryer because of fire and explosion hazard, but also for some of the other operations--e.g., grinding, screening, tabling, or packing.

If the starch dryer were placed in a separate building, the space allotted to it would be available for settling tanks. The arrangement of facilities outside the building is subject to change, depending on location of wagon roads, railroad spur, and topography of factory site. If a hillside delivery can be made to the factory, a fluming system is unnecessary. In small plants where principal potato delivery is by wagon or truck, primary consideration must be given to convenience of unloading such vehicles; potatoes delivered in railroad cars could be discharged direct into the flume. In large factories where a much greater proportion of potatoes is delivered in large trucks or railroad cars, a more convenient arrangement can be made.

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